

ATK Engineering, NASA Programs, Engineering Examples

David Richardson, ATK Launch Systems

ABSTRACT:

This presentation provides an overview of the work done at ATK Launch Systems with an indication of how engineering knowledge can be applied to several real world problems. All material in the presentation has been screened to meet ITAR restrictions. The information provided is a compilation of general engineering knowledge and material available in the public domain. The presentation provides an overview of ATK Launch Systems and NASA programs. Some discussion is provided about the types of engineering conducted at the Promontory plant with added detail about RSRM nozzle engineering. Some brief examples of examples of nozzle technical issues with regard to adhesives and phenolics are shared.

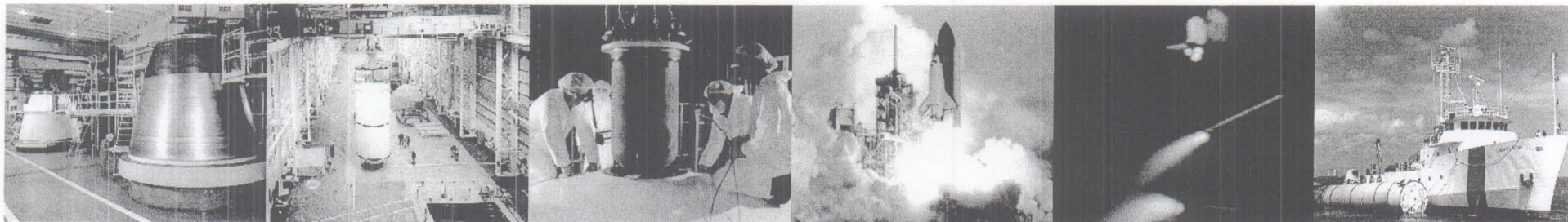
These technical issue discussions are based on material available in the public domain.



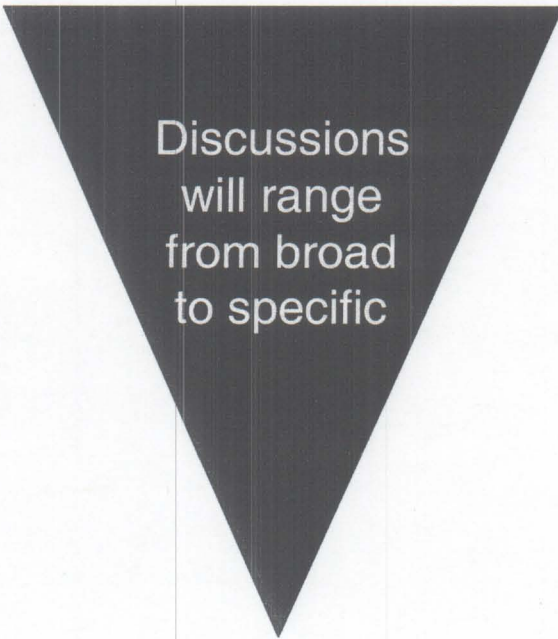
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ATK Launch Systems Engineering NASA Programs Engineering Examples

David Richardson
April 16, 2007



- Objective: Provide an overview of the work done at ATK Launch Systems with and indication of how engineering knowledge can be applied to several real world problems
 - Restriction – material in presentation has been screened to meet ITAR restrictions
 - Specifics of rocket motor design, processing, etc. have been left out
 - Information will be a compilation of general engineering knowledge and material available in the public domain
- Outline
 - Provide an overview of ATK Launch Systems
 - Review NASA programs in general
 - Discuss engineering at Promontory plant
 - Provide overview of nozzle engineering
 - Examples of nozzle technical issues
 - Adhesives
 - Composites



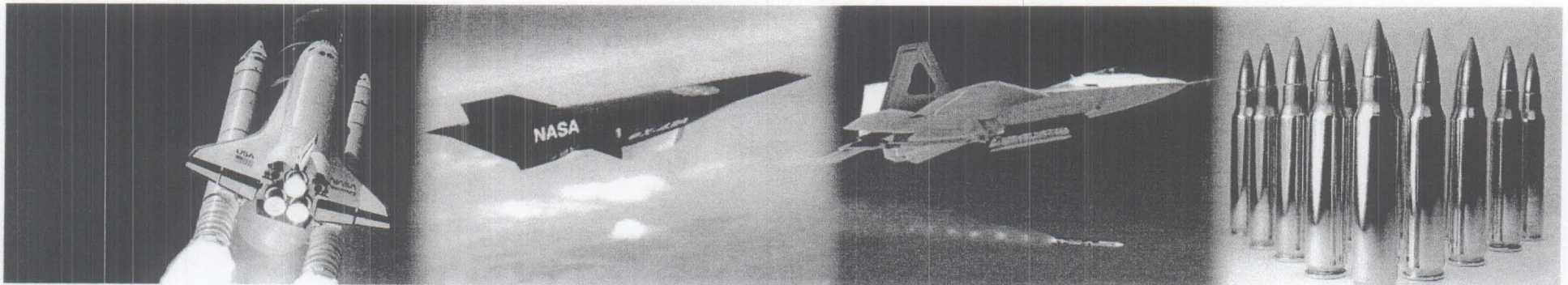
Discussions
will range
from broad
to specific

ATK Corporate Profile



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- \$3.4 billion aerospace and defense company
- ~15,000 employees
- Headquarters in Edina, MN
- Ranked 13th largest U.S. defense contractor by *Defense News*
- Ranked 9th largest world space company by *Space News*



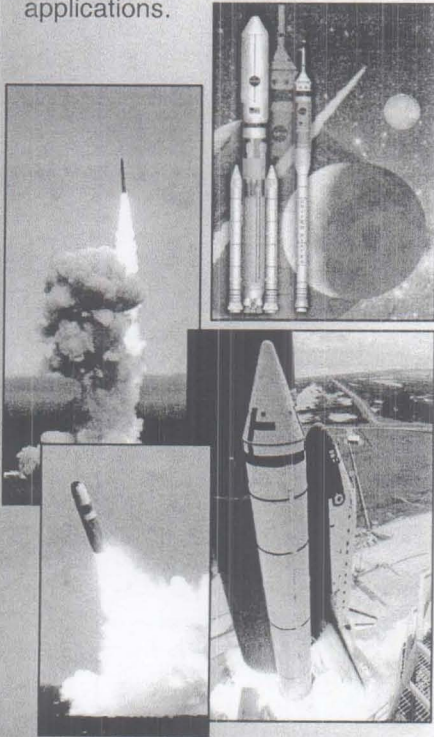
ATK Corporate Structure



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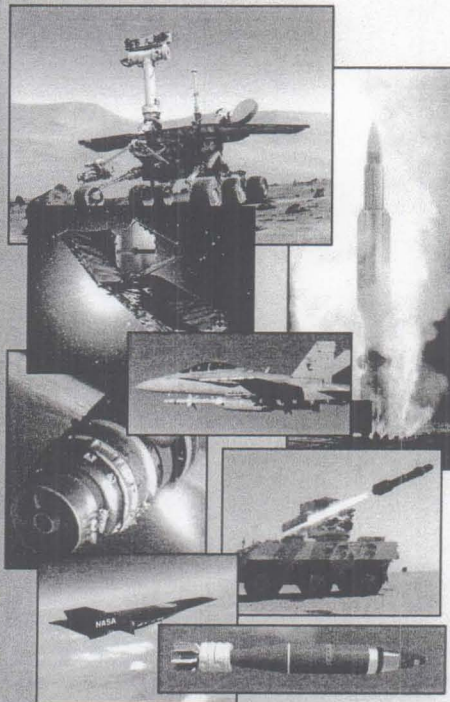
Launch Systems

The world leader in the design, development, and production of launch systems for space, strategic, and missile defense applications.



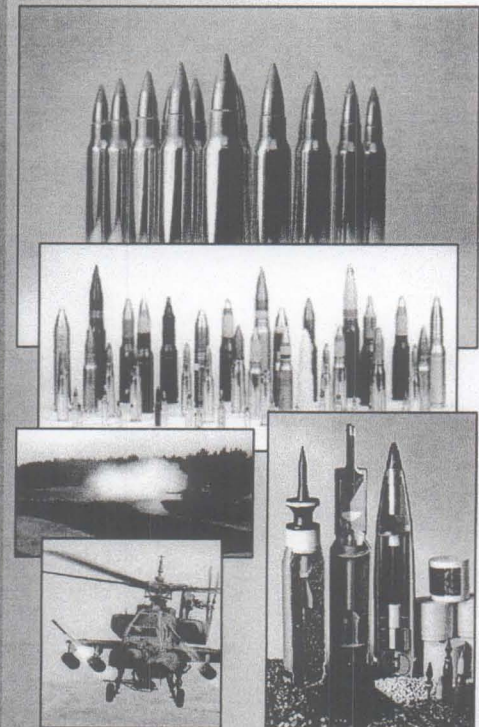
Mission Systems

Pioneering advanced solutions for access to space and delivering greater power, precision, and performance to America's fighting forces.

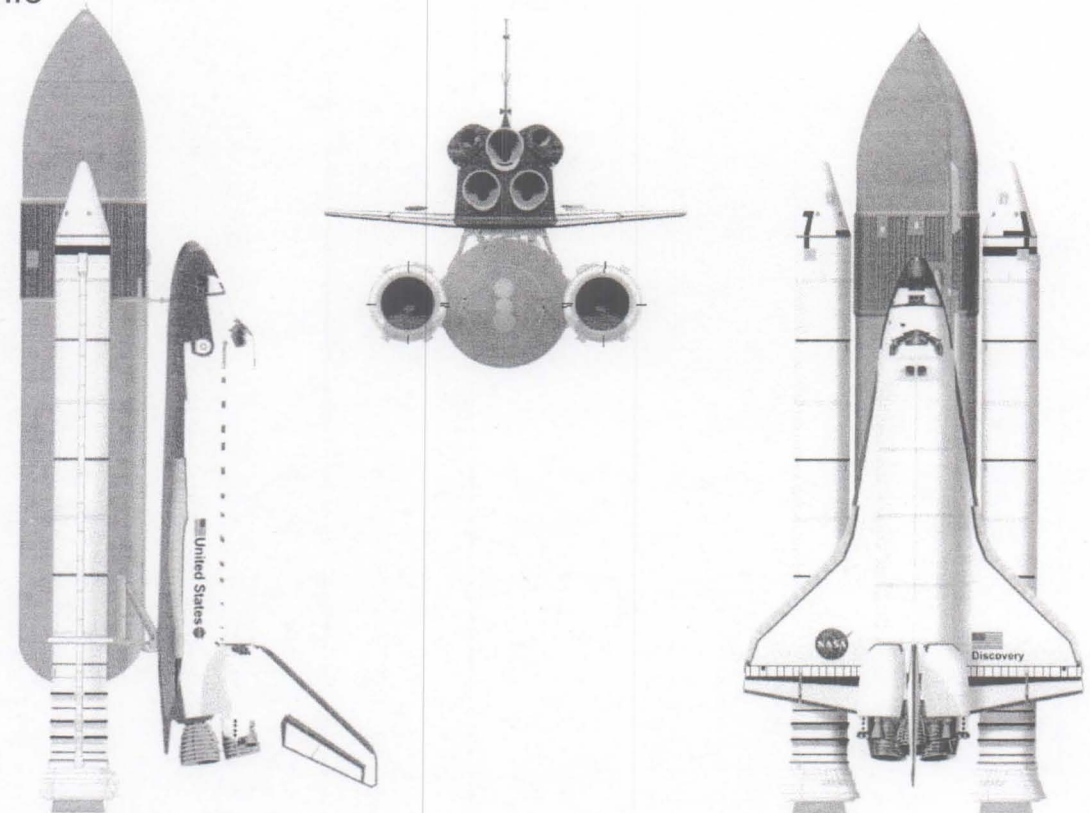


Ammunition Systems

The nation's largest producer of conventional munitions, serving both the military and commercial markets.



- The *WORLD LEADER* in solid propulsion systems and unequalled expertise in...
 - Engineering design and system analysis
 - Systems engineering and integration
 - Energetic materials and pyrotechnic systems
 - Composite materials and structures
 - High-strength metals
 - High-temperature materials
 - Adhesives
 - Insulators
 - Ablatives
 - Thermal protection systems
 - Integrated vehicle health management



Promontory Facilities



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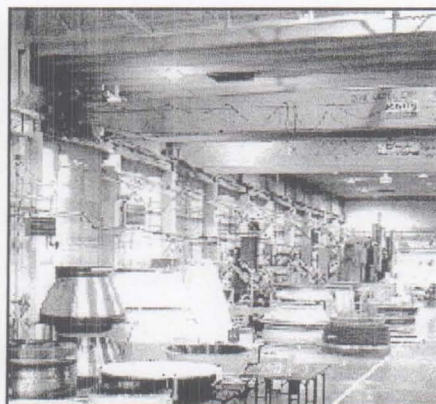
- 3,250 employees
- 535 buildings
- 19,900 acres
- 2.5 million ft² of manufacturing facilities
- 300,000 ft² of R&D laboratories



Promontory Rocket Display



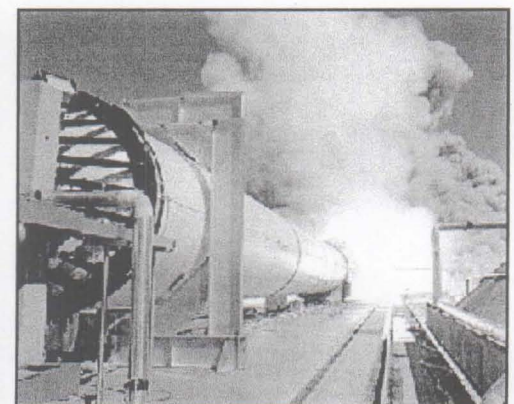
Design



Nozzle



Mix/Cast



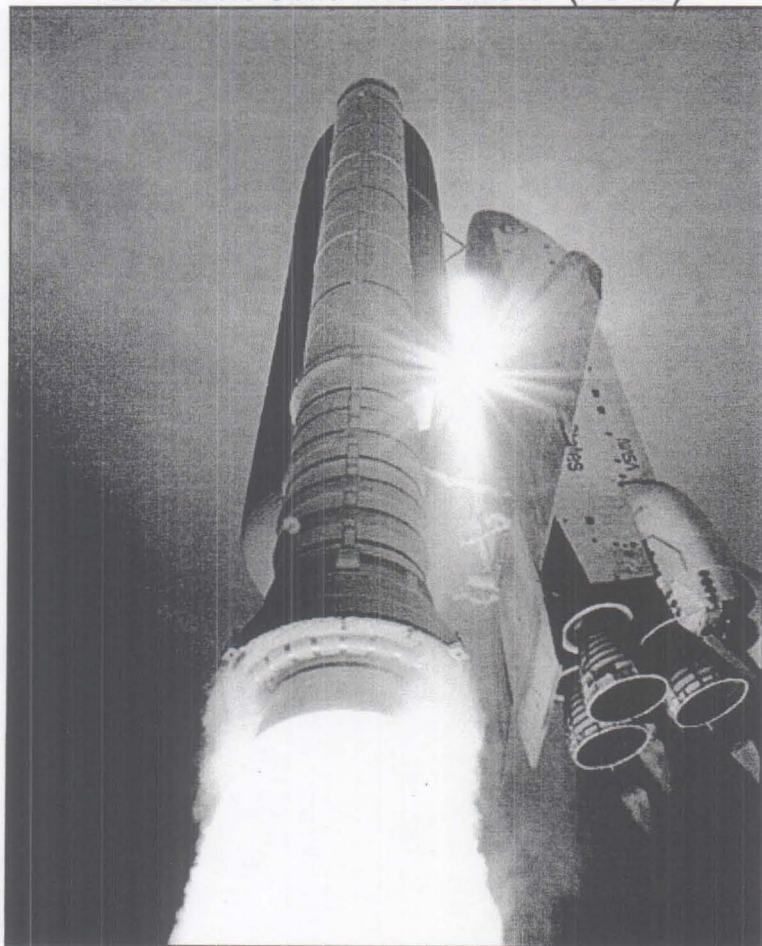
Test Operations

NASA Programs - Today

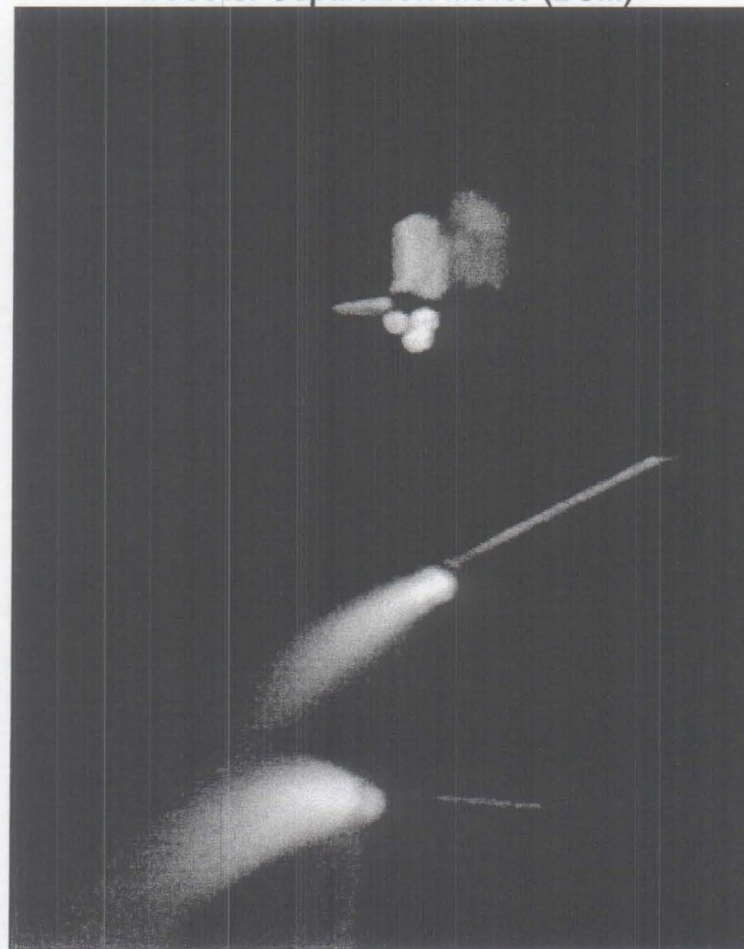


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Reusable Solid Rocket Motor (RSRM)



Booster Separation Motor (BSM)

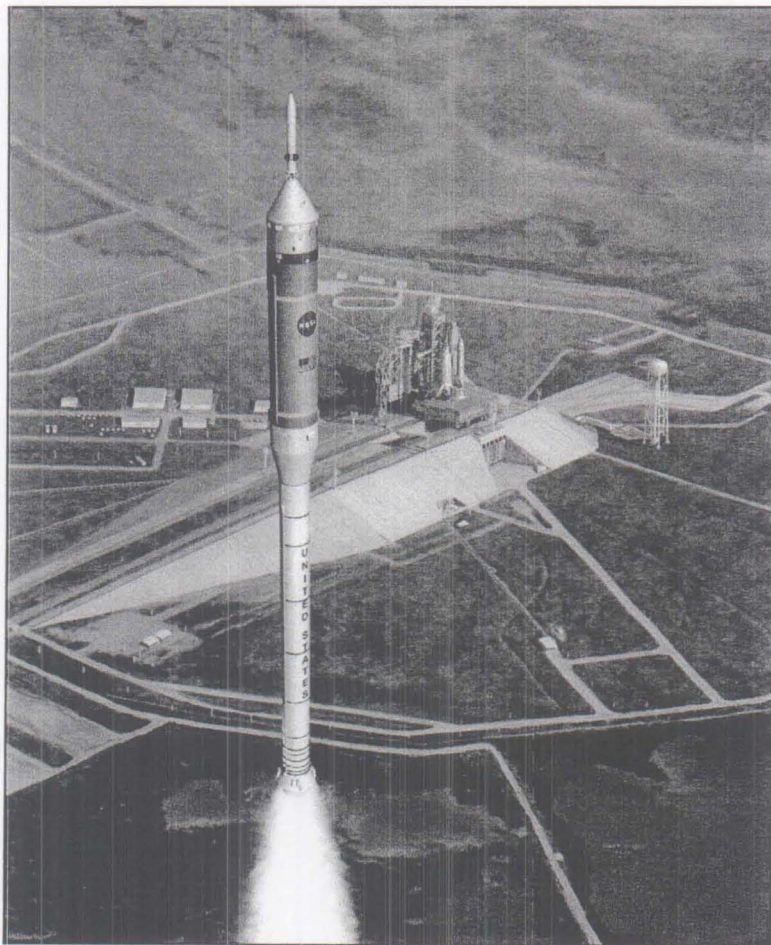


NASA Planned Programs - Tomorrow

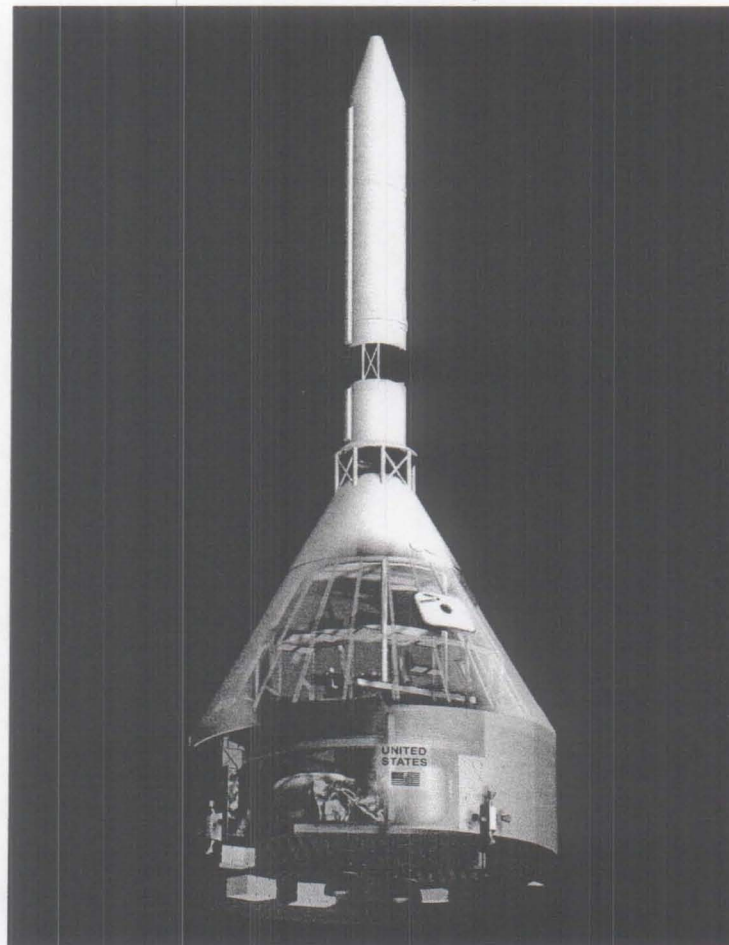


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Ares I Stage 1



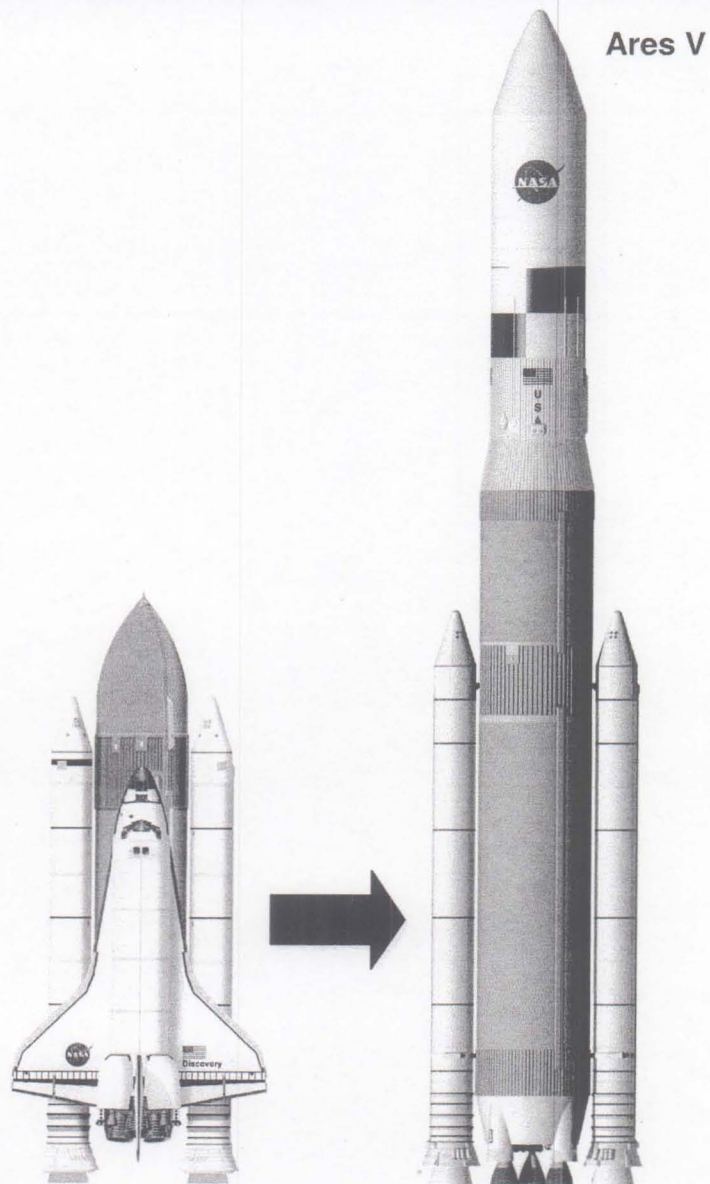
Launch Abort System



NASA Programs - Future



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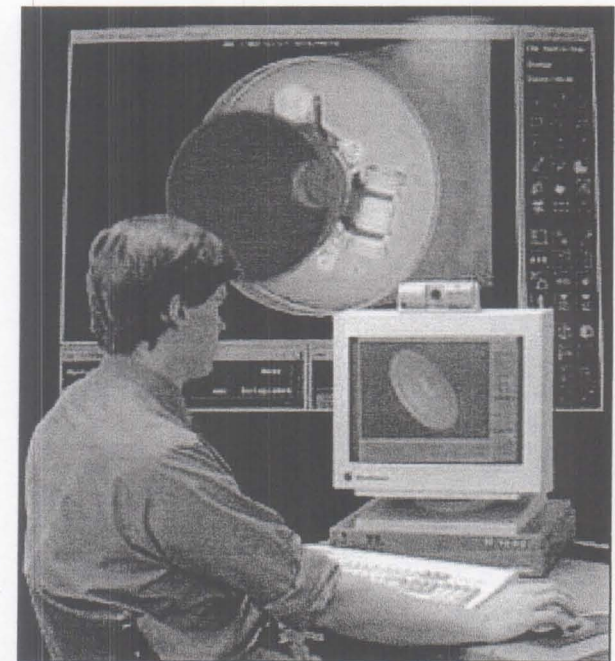
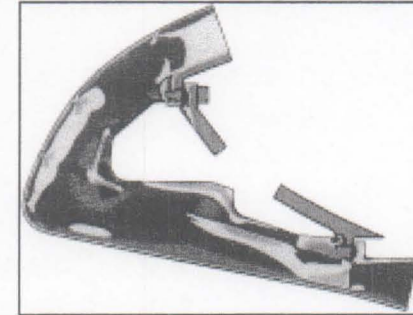
Science and Engineering Capabilities



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- Over 900 scientists, engineers, and technicians
- Automated preliminary design and analysis tools
- System analysis capability
- Computer-aided design and data management
- Sophisticated materials, aero, thermal, and structural analysis tools
- Complete laboratory and testing facilities and capabilities

Finite Element Analysis Results



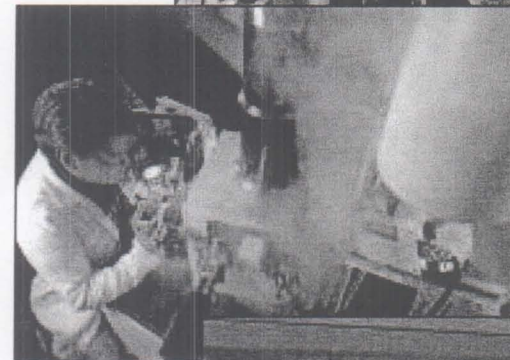
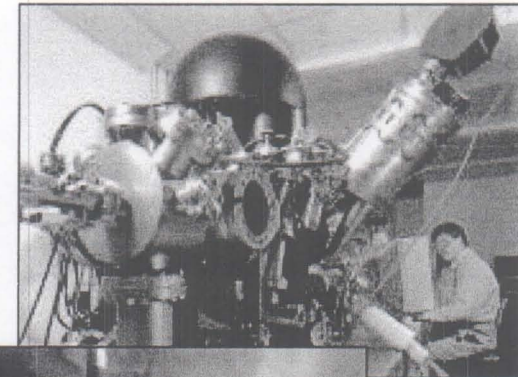
Computer Aided Design

S&E Research and Development Capabilities

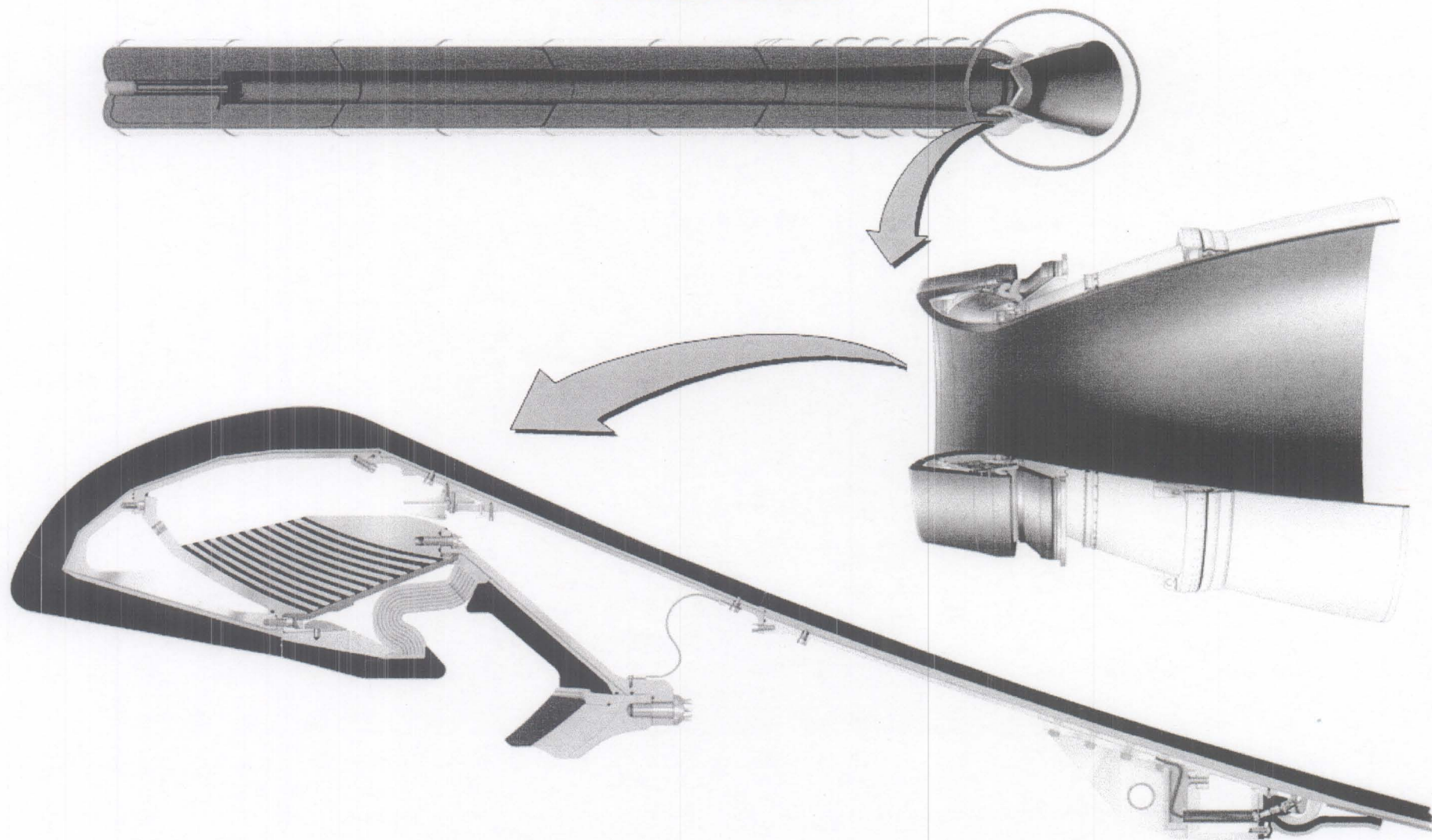


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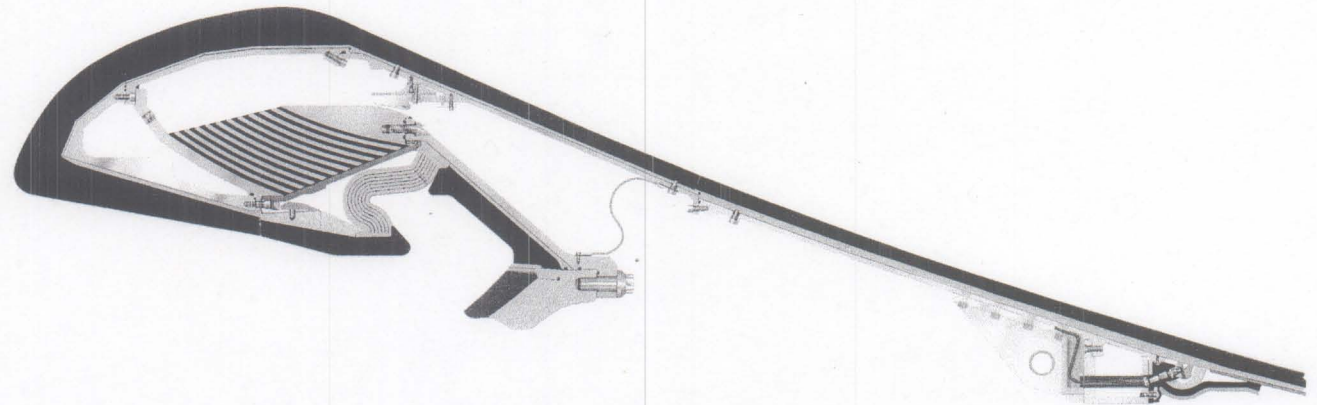
- Industry leader in solid rocket motors and related technologies
 - World leader in solid rocket propellant development
 - Highest performing composite case technologies
 - Innovative nozzle/ablative materials technologies
 - Metallurgical, corrosion, and metal restoration expertise
 - World-class bonding and adhesive development capabilities
 - Extensive experience developing high-temperature materials and insulation
 - Industry leader in new energetic materials development
 - High-temperature thermal protection system materials technology



RSRM Nozzle



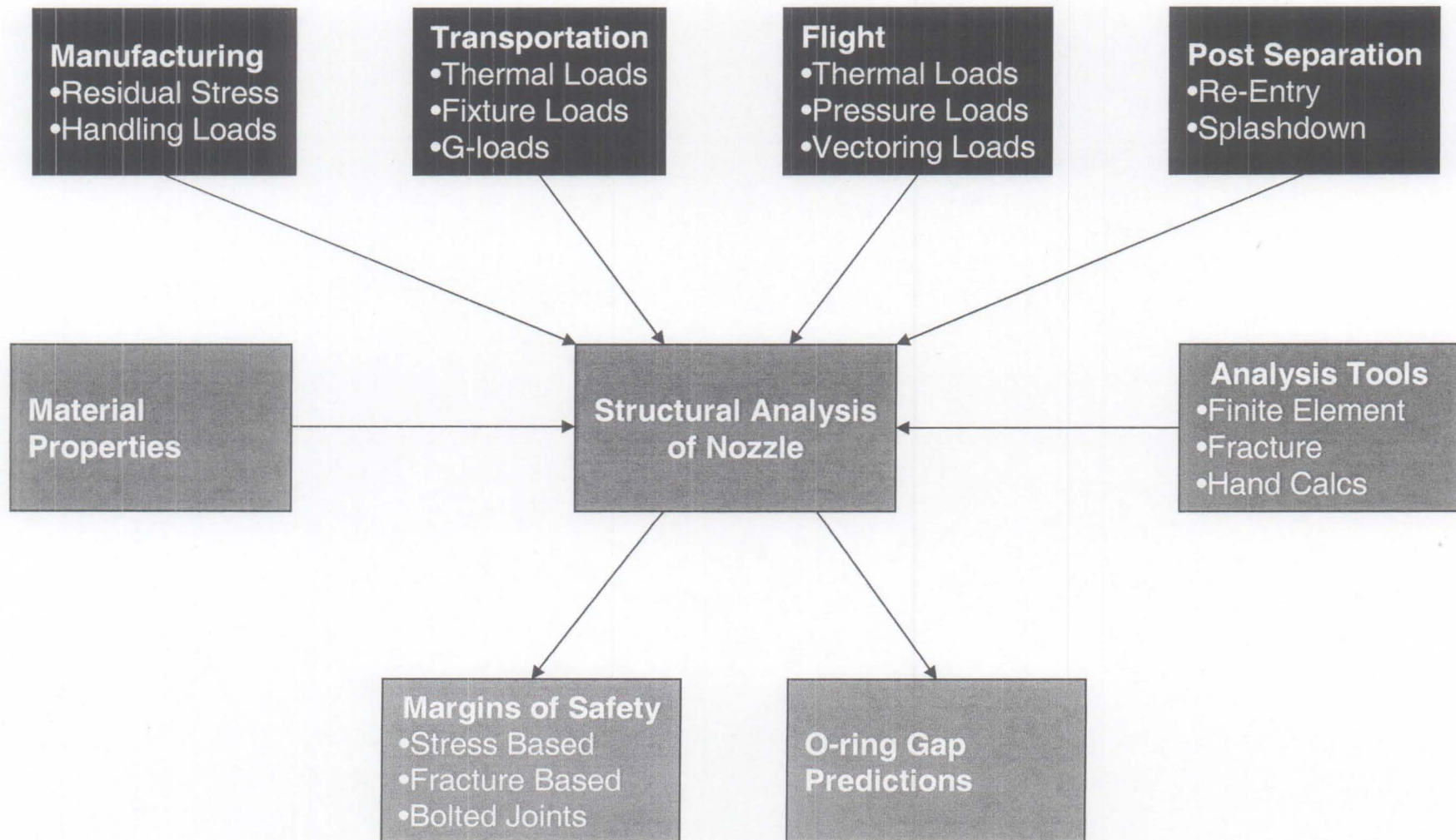
- Task
 - Design nozzle
 - Designing next ARES nozzles
 - Control materials
 - Numerous materials
 - Evaluate discrepancies
 - Process is complex
 - Address obsolescence
 - Develop processes
 - Large parts, complex procedures
 - Define inspections
 - Visual, NDE, destructive



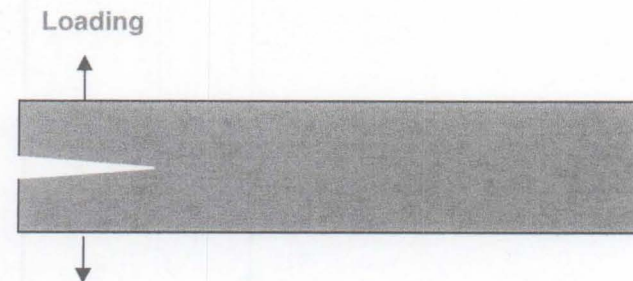
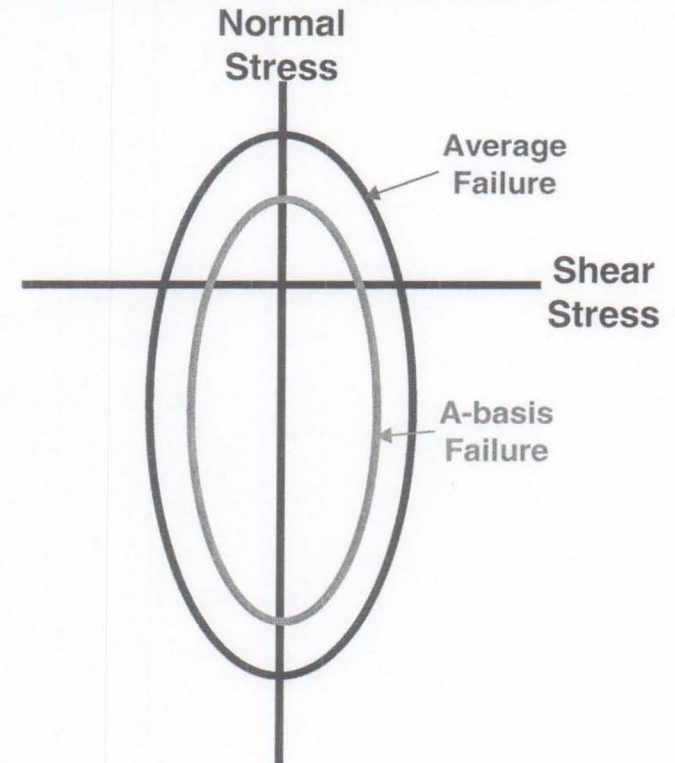
Nozzle - Structural Analyses



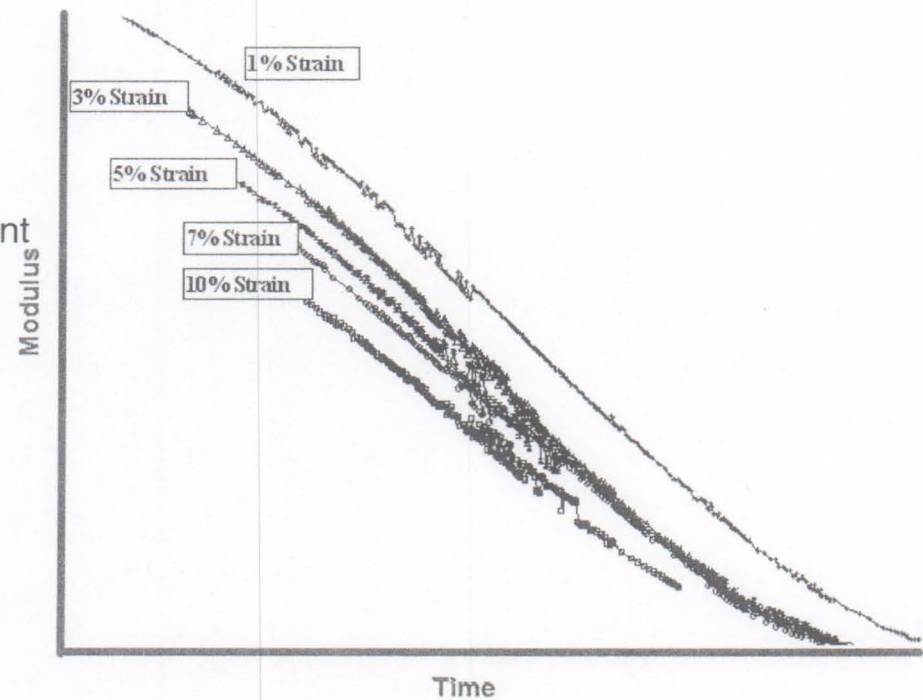
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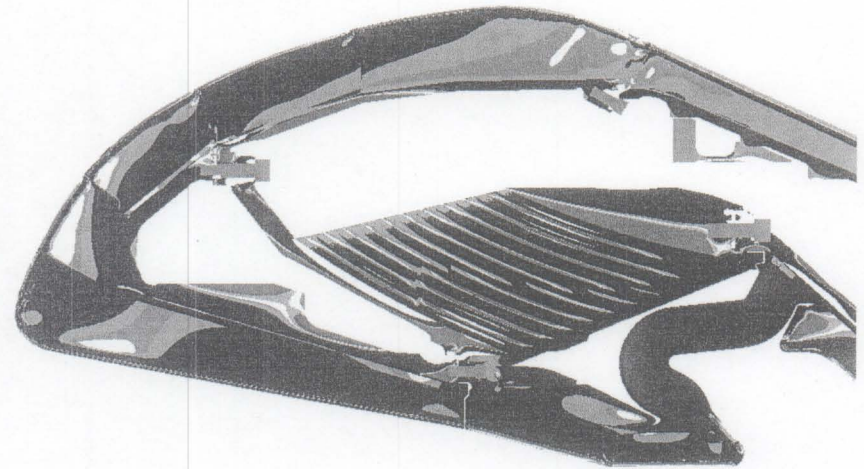
- Constitutive model - phenolics
 - Ablative liners -20°F to 4,500°F
 - Material changes
 - Pyrolysis
 - Nonlinear models
 - Yielding
 - Tension/compression
- Failure model - phenolics
 - Failure criterion: accounts for multi-axial loading (3D Tsai-Wu)
- Fracture model - phenolics
 - Evaluate cracks, discontinuities, etc.
 - Mode I assumed to be conservative



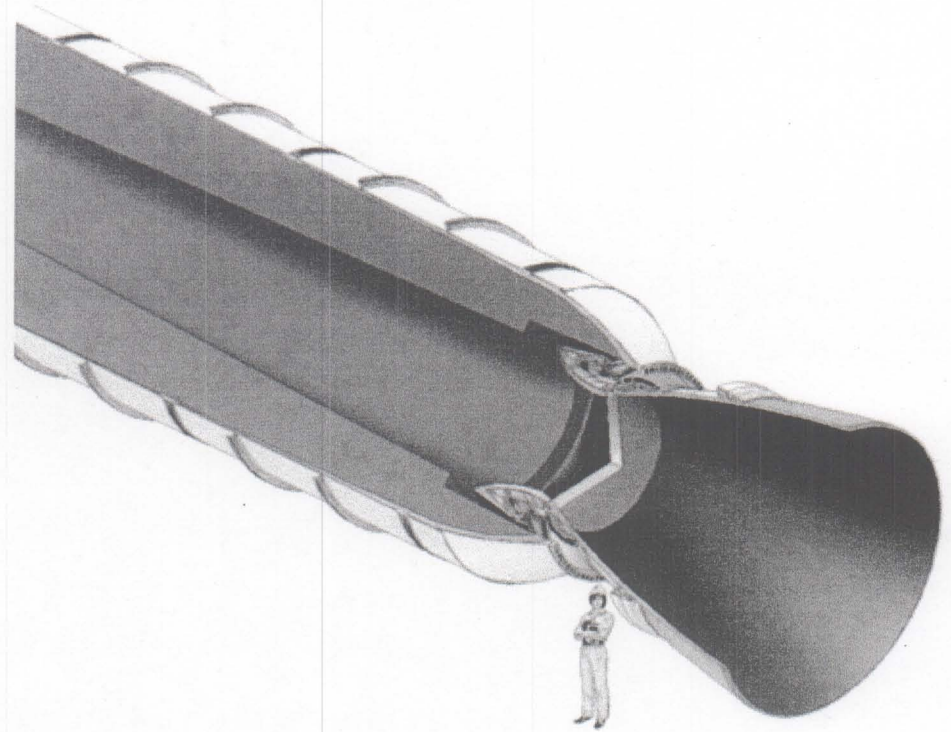
- Constitutive model - adhesives
 - Time and temperature dependent
 - Linear models (approximations)
 - Nonlinear viscoelastic models
- Failure models - adhesives
 - Multi-axial temperature and time (MATT) dependent failure criterion
 - Radial bondlines not considered structural
- Fracture model - adhesives
 - Evaluate cracks, discontinuities, etc.
 - Mode I assumed to be conservative



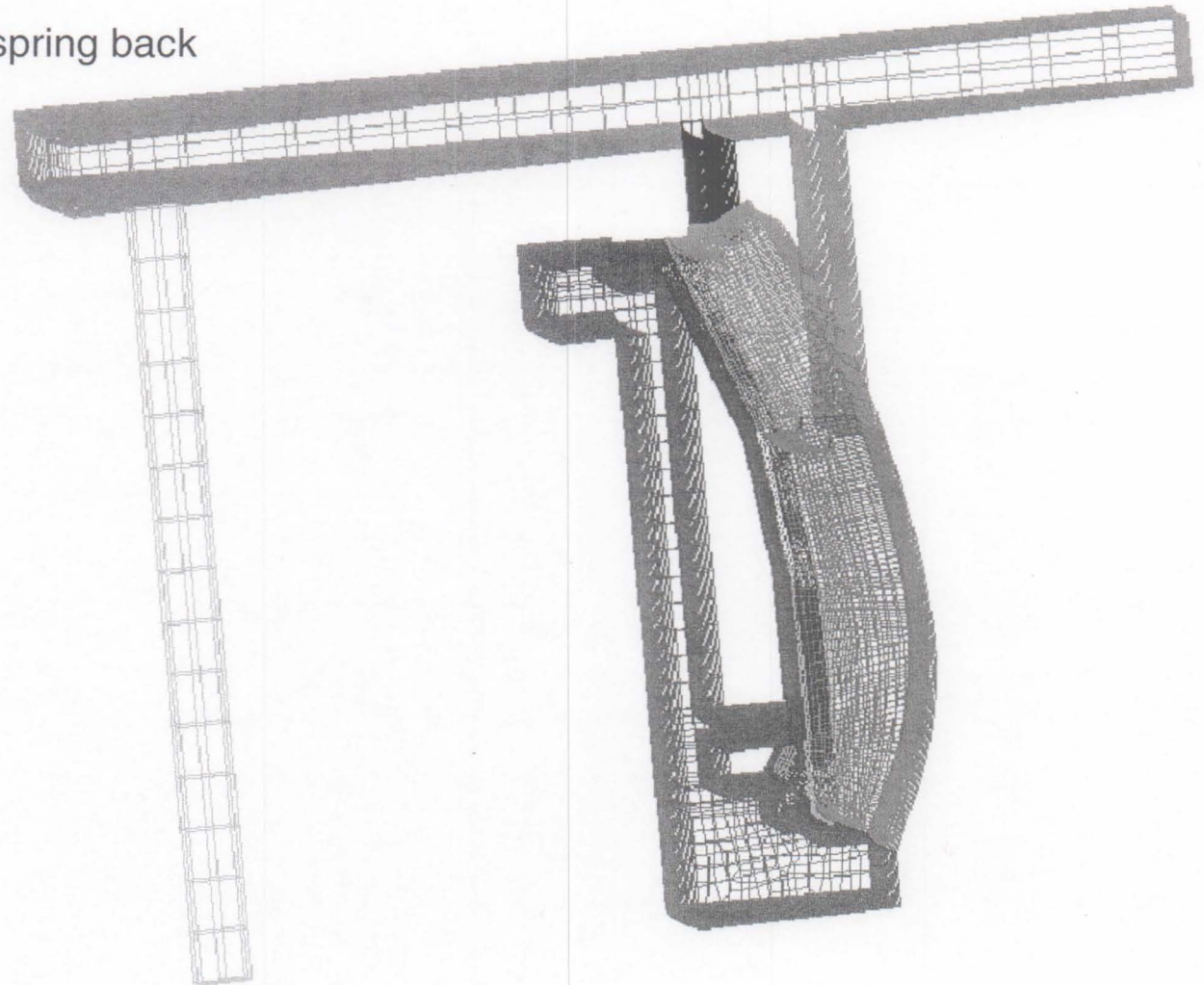
- Statistical inputs
 - A-basis input properties
 - 99% probability with 95% confidence
 - Used where conservatism can be ensured
 - Material capabilities



- Residual stresses induced during manufacturing
 - Massive parts deflected prior to bonding
 - Upon release, residual stresses are induced
- Complex material models
- Loading conditions
 - Many sources of stresses
 - 3-D effects confound analyses
 - Boundary conditions not simple
 - Worst on worst superposition

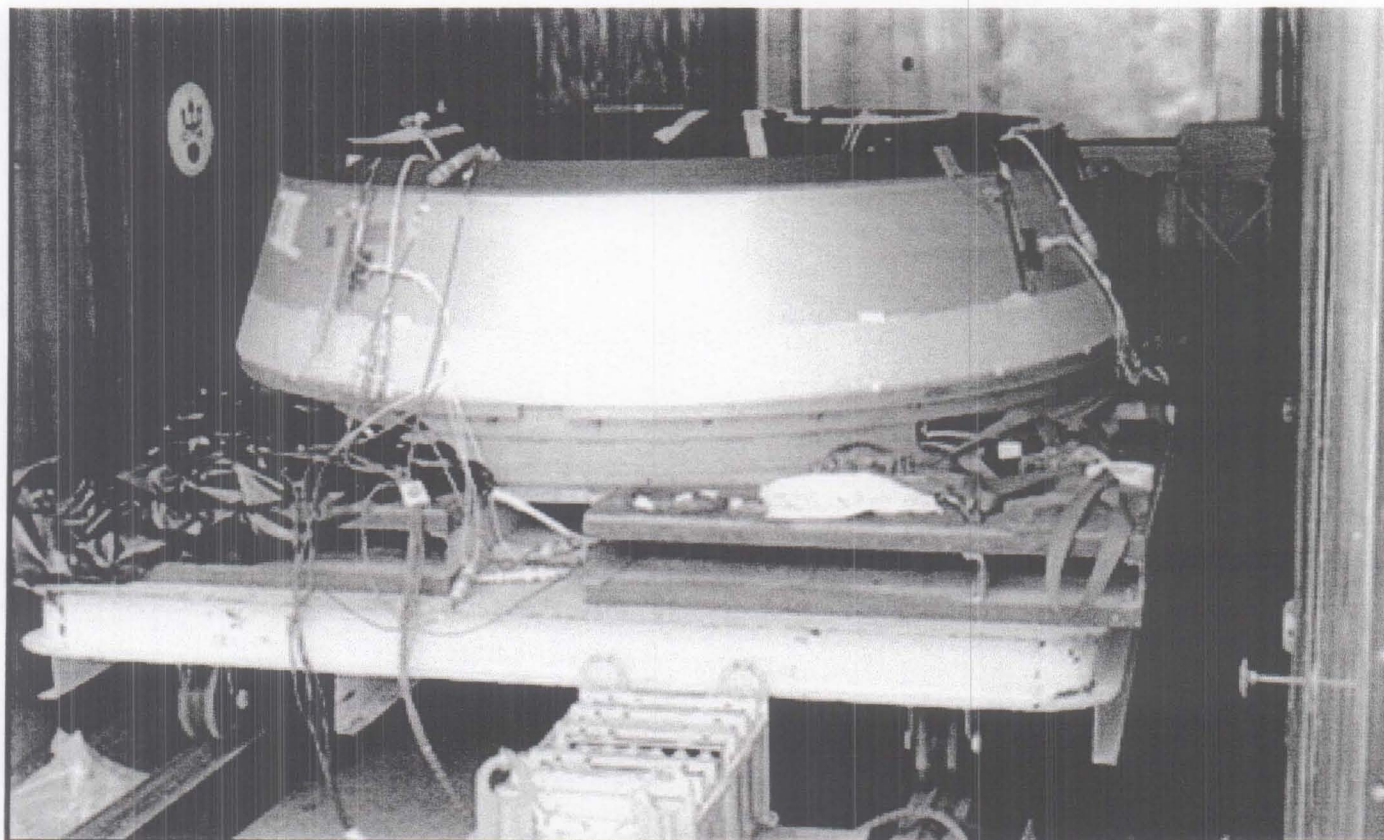


- Bonding induces residual stresses
 - Deflected components spring back
- Complex process
 - 3-D
 - Nonlinear
 - Multiple step

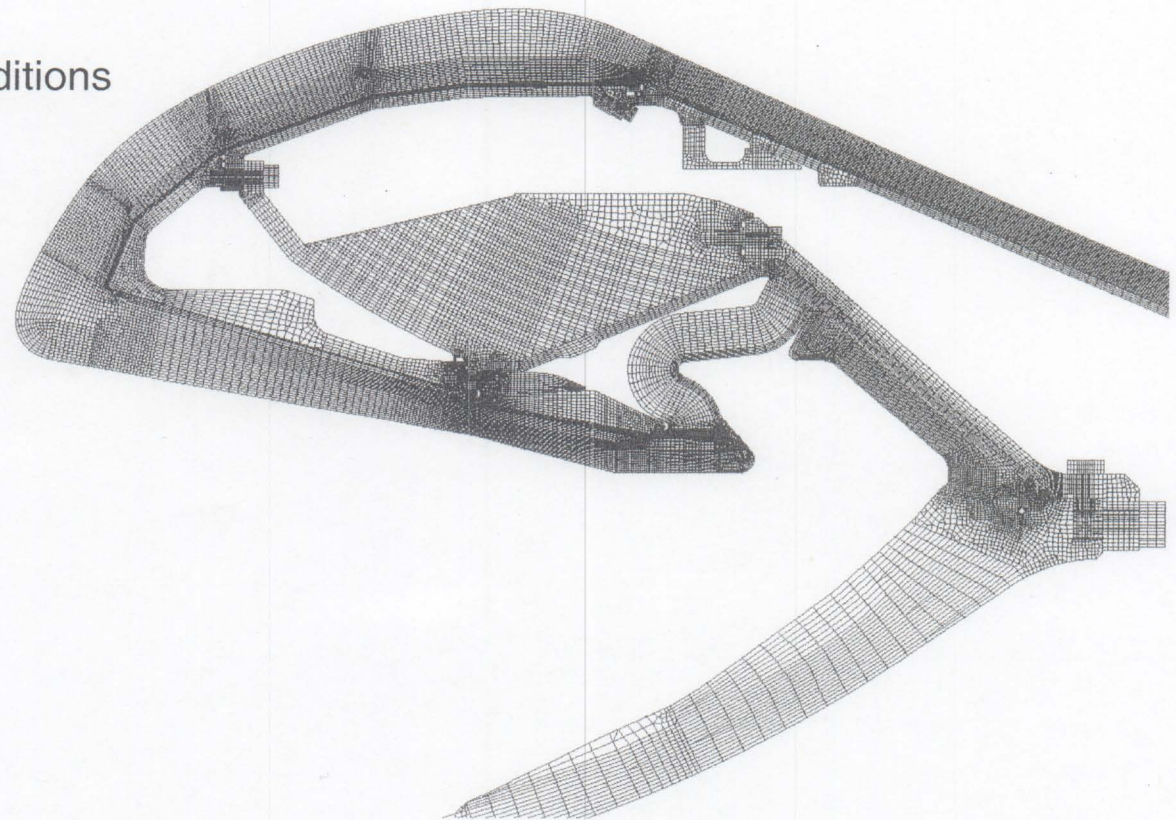


- Extensive verification has been conducted to evaluate accuracy of residual stress analyses
 - Full-scale testing
 - Subscale testing

Full-Scale Nozzle Bond Residual
Stress Simulation Test



- Analysis
 - Extreme temperatures
 - High pressures
 - Nonlinear material
 - Nonlinear boundary conditions

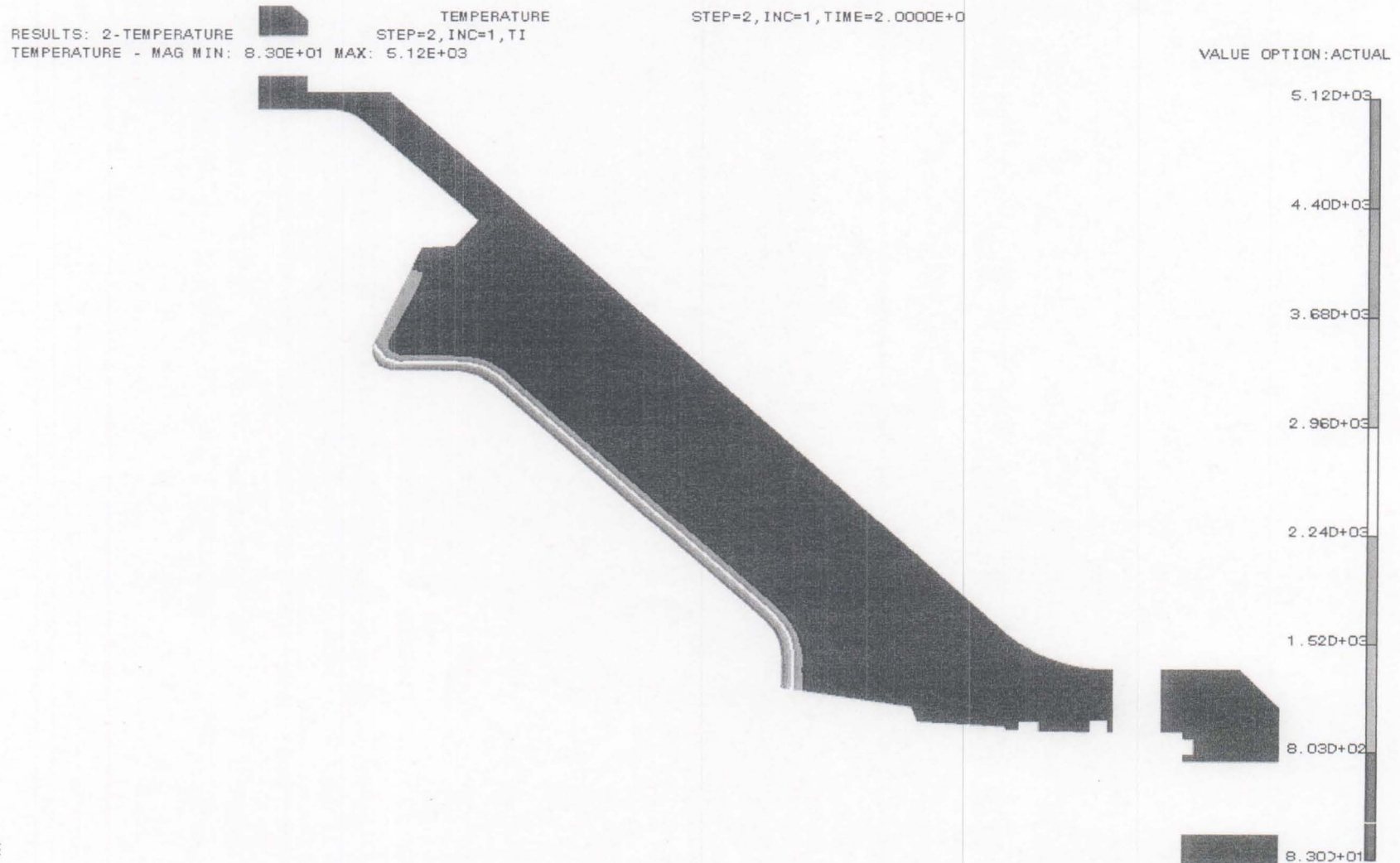


Flight Analyses: Thermal Input



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- Typical thermal input

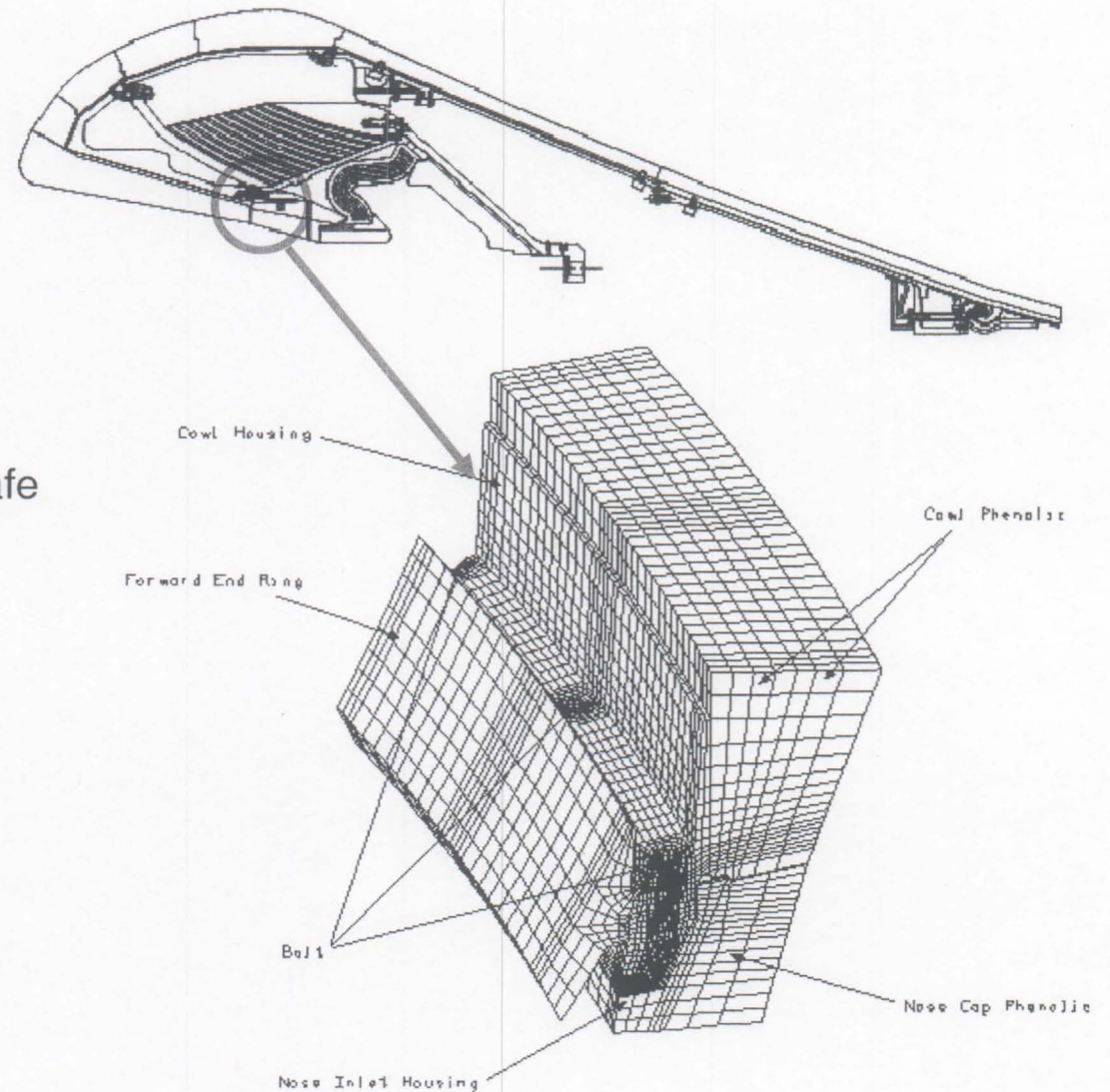


Bolted Joints

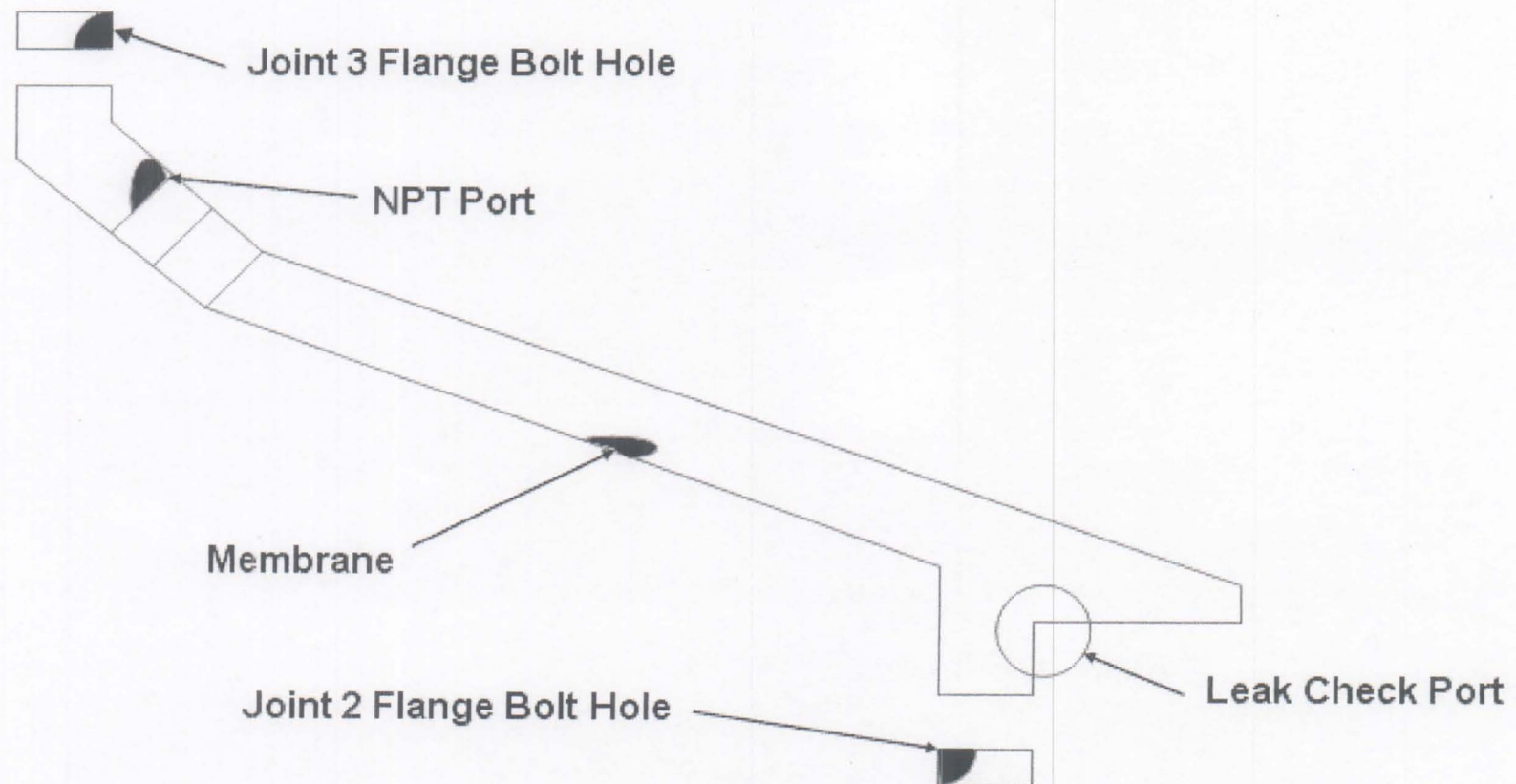


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- Model
 - 3-D
 - Joint skip
 - Contact (heads, shanks, threads, and flanges)
 - Joint opening
- Analyses show joints are fail-safe



- Fracture calculations made for metal components
 - Critical flaw sizes
 - Fatigue crack growth

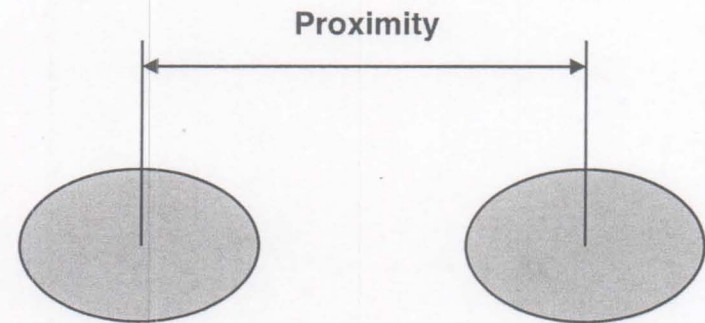
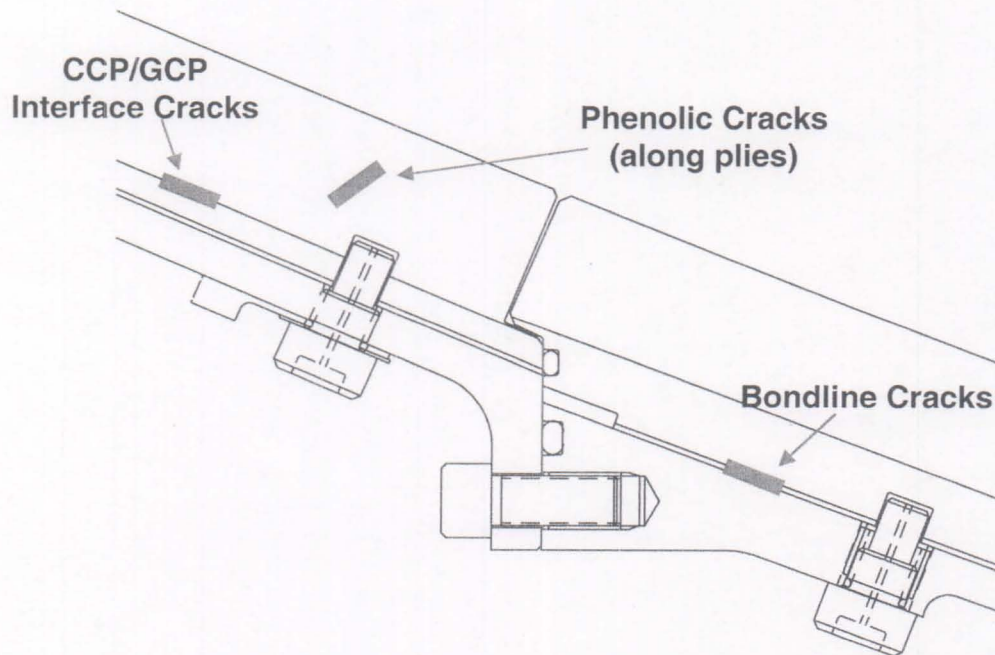


Phenolic and Bondline Fracture



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- Phenolic and bondline fracture analyses
 - Composite fracture evaluated
 - Bi-material interface fracture evaluated
 - Effects of proximity of discontinuities are mathematically modeled



- Failure criterion required to address all conditions that influence failure
 - Multi-axial loading
 - Temperature changes
 - Loading times
- Required development of new generalized failure model

MATT failure criterion approved by NASA for public release and documented in AIAA Journal, Journal of Adhesion, and proceedings for AIAA JPC and Adhesion Society Meetings

- MATT failure criterion

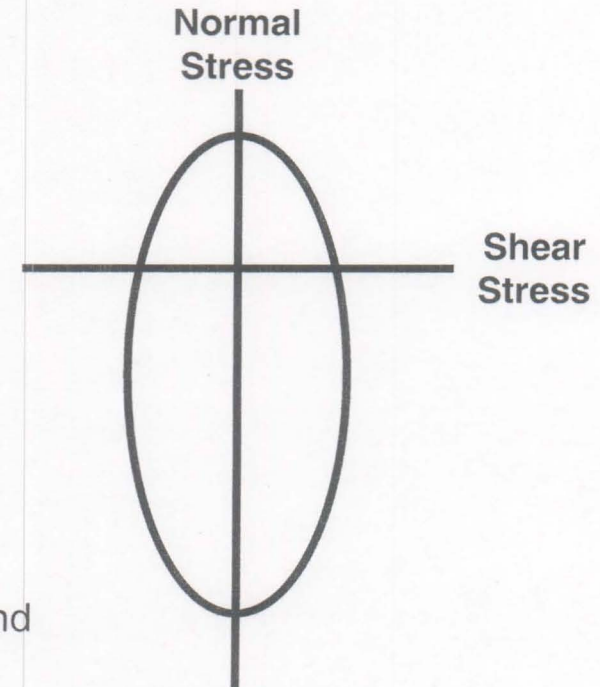
$$AP^2J_2 + BPI_1 = 1$$

J_2 = Second deviatoric stress invariant

I_1 = First stress invariant

A,B = Shape parameters (from normal and shear test data)

P = Size parameter or scale factor (function of temperature and time)



$$I_1 = \sigma_{11} + \sigma_{22} + \sigma_{33}$$

$$J_2 = \frac{1}{3} \left[\begin{array}{c} \sigma_{11}^2 + \sigma_{22}^2 + \sigma_{33}^2 - \\ \sigma_{11}\sigma_{22} - \sigma_{11}\sigma_{33} - \sigma_{22}\sigma_{33} + \\ 3\sigma_{12}^2 + 3\sigma_{13}^2 + 3\sigma_{23}^2 \end{array} \right]$$

MATT failure criterion approved by NASA for public release and documented in AIAA Journal, Journal of Adhesion, and proceedings for AIAA JPC and Adhesion Society Meetings

$$AP^2J_2 + BPI_1 = 1$$

- Linear cumulative damage (to characterize P)

- Equation

$$N_\sigma = \left[\int_0^{t_f} \sigma_i^\beta dt \right]^{1/\beta}$$

- Constant Rate

$$t_f = (1 + \beta) \left[\frac{N_\sigma}{\sigma_f} \right]^\beta \quad \sigma_f = N_\sigma \left[\frac{t_f}{1 + \beta} \right]^{-1/\beta}$$

- Constant Load

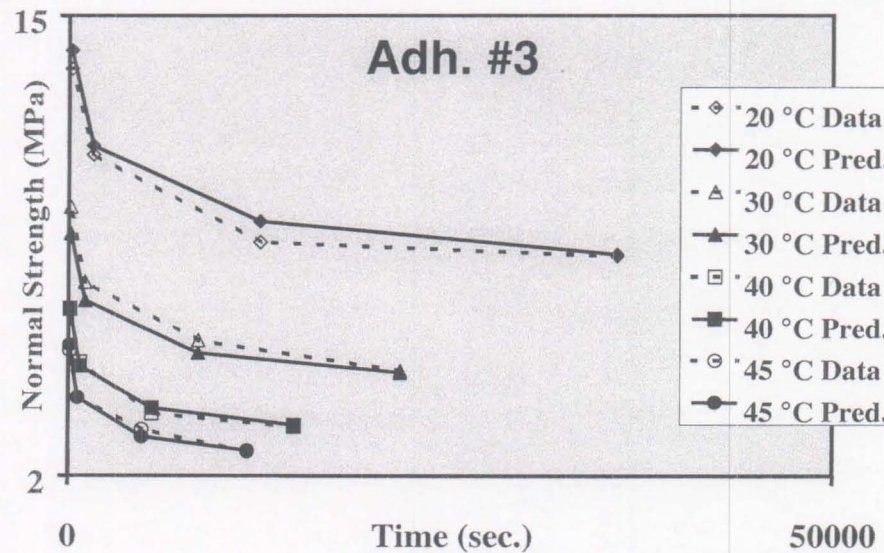
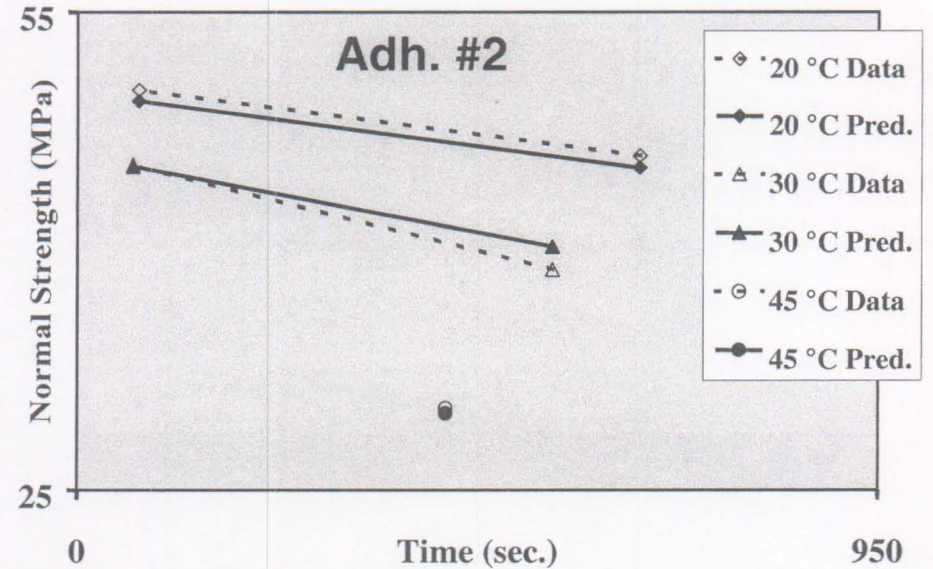
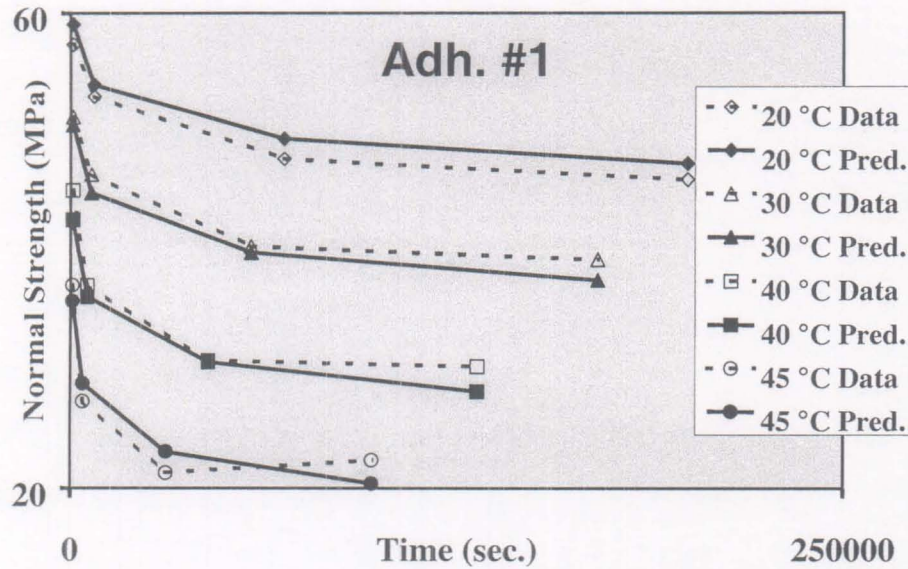
$$t_f = \left(\frac{N_\sigma}{\sigma_f} \right)^\beta \quad \sigma_f = N_\sigma t_f^{-1/\beta}$$

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Adhesives - Failure Model: Tensile Adhesion



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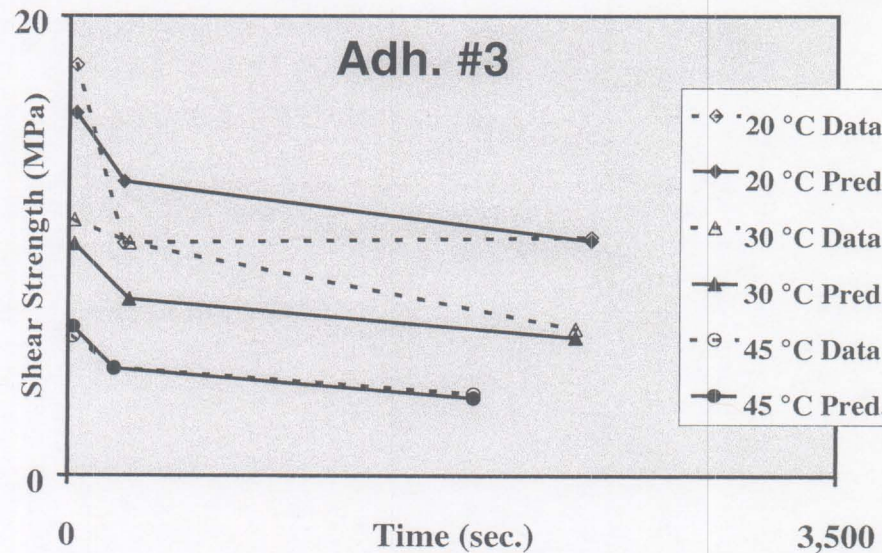
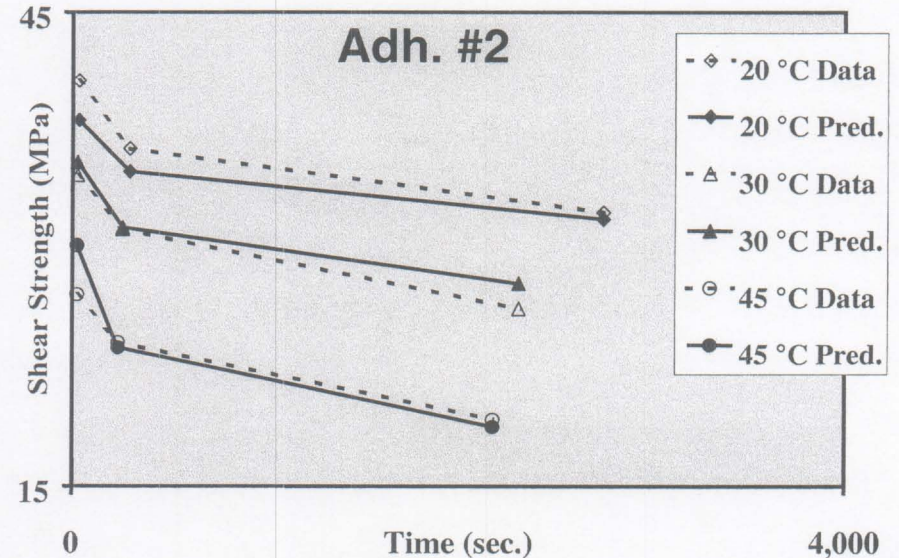
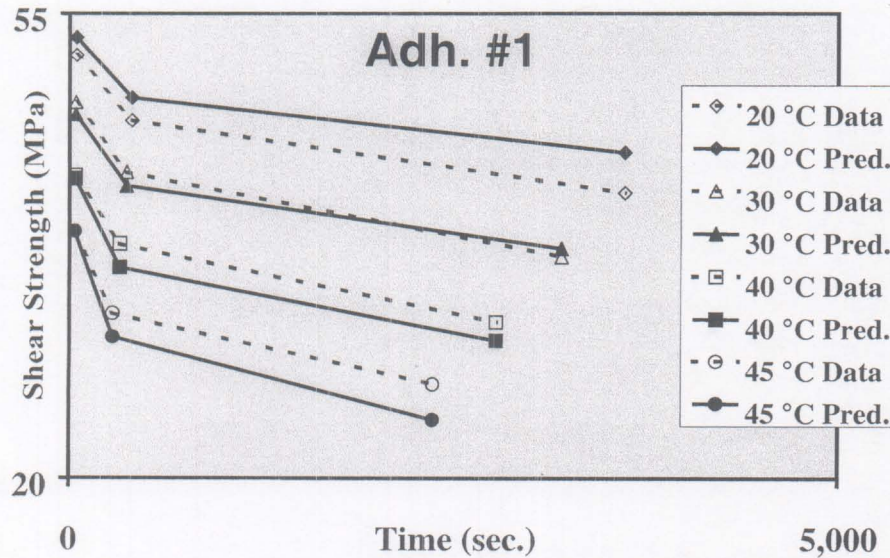


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Adhesives - Failure Model: Shear Adhesion



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Coefficients of Variation for the Tensile Adhesion and Shear Adhesion Tests

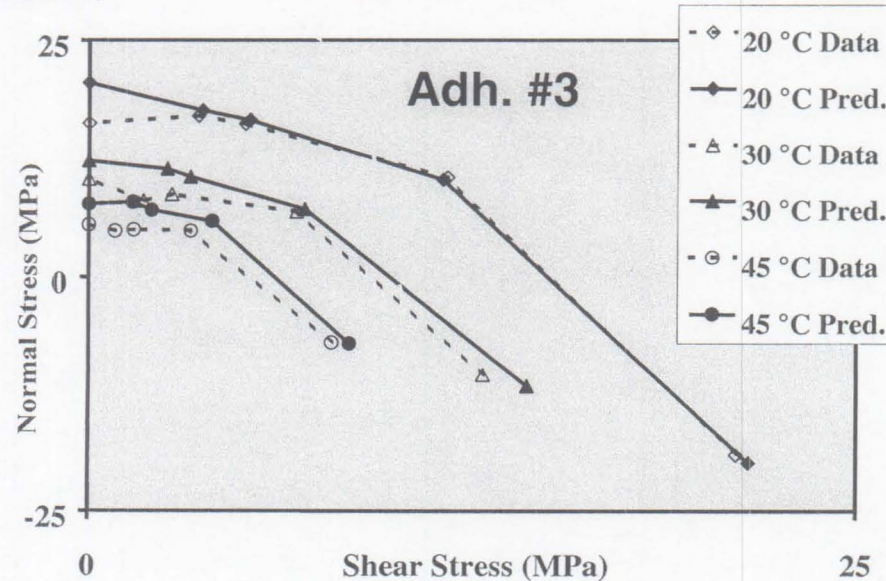
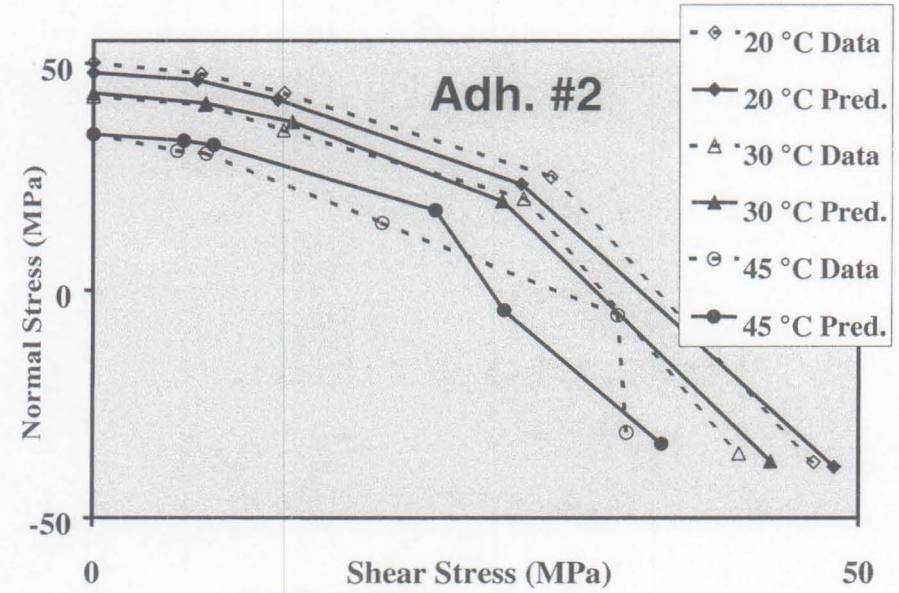
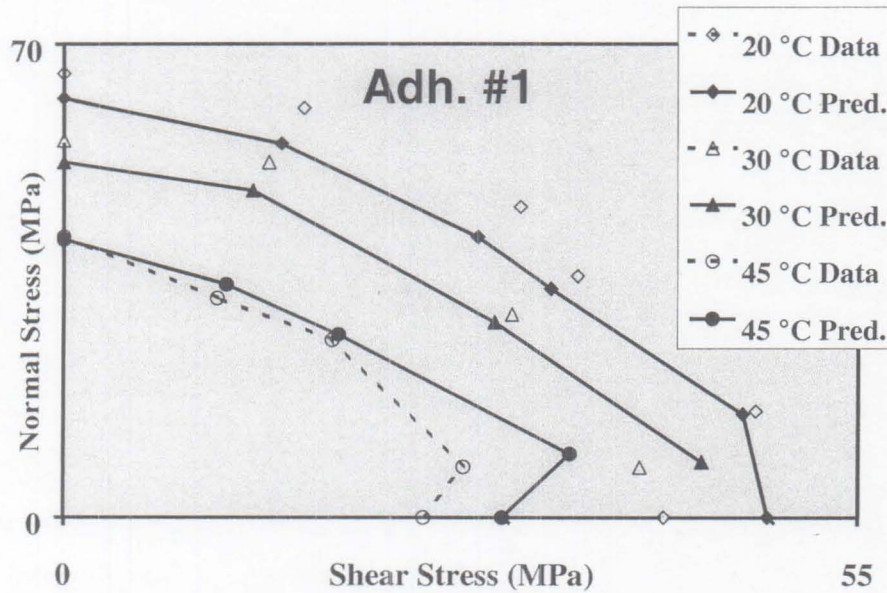
Adhesive	Tensile COV	Shear COV	Tensile Count	Shear Count
Adh. #1	9%	11%	206	178
Adh. #2	7%	7%	20	45
Adh. #3	10%	22%	79	41

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Adhesives - Verification: Multi-Axial



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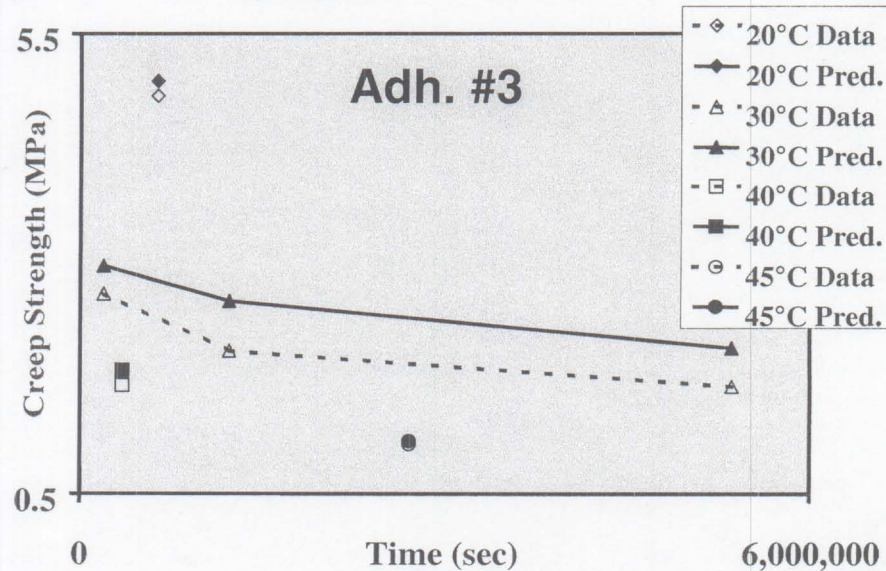
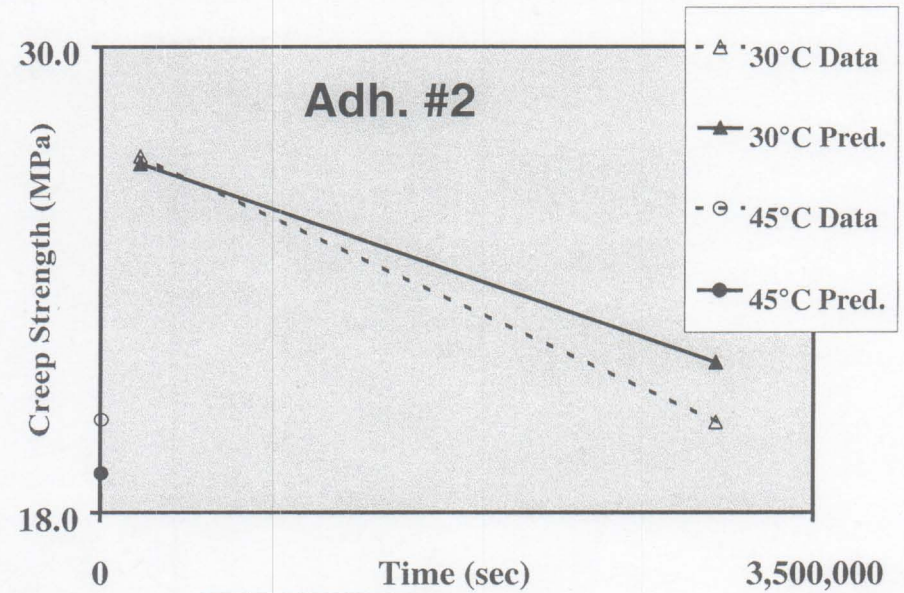
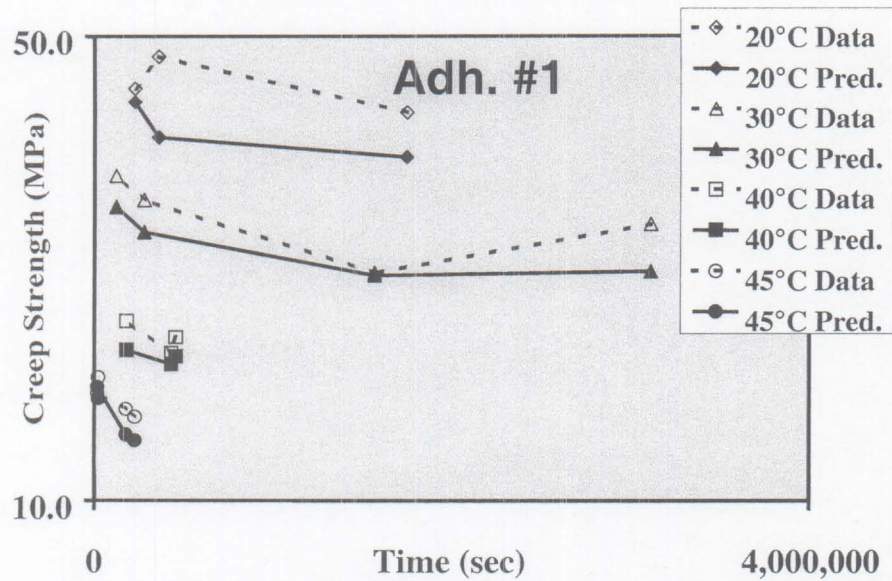


MATT failure criterion approved by NASA for public release and documented in AIAA Journal, Journal of Adhesion, and proceedings for AIAA JPC and Adhesion Society Meetings

Adhesives - Verification: Creep



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Coefficients of Variation for the Multi-Axial and Creep Tests

Adhesive	Multi-Axial COV	Creep COV	Multi-Axial Count	Creep Count
Adh. #1	13%	15%	56	104
Adh. #2	11%	21%	57	8
Adh. #3	23%	20%	50	34

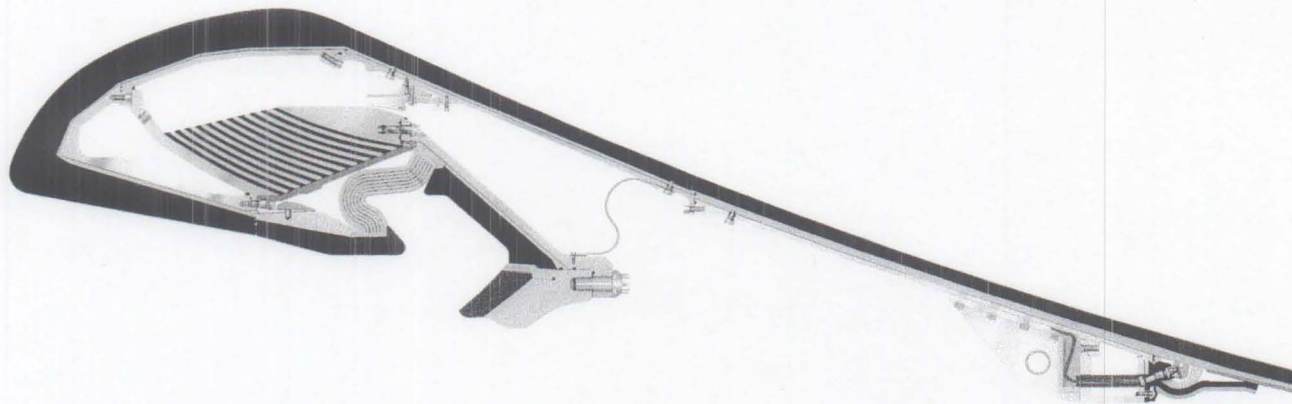
MATT failure criterion approved by NASA for public release and documented in AIAA Journal, Journal of Adhesion, and proceedings for AIAA JPC and Adhesion Society Meetings

Coefficients of Variation for All Tests

Adh. #1	Adh. #2	Adh. #3	Adh. #1 Count	Adh. #2 Count	Adh. #3 Count
11%	9%	17%	544	130	204

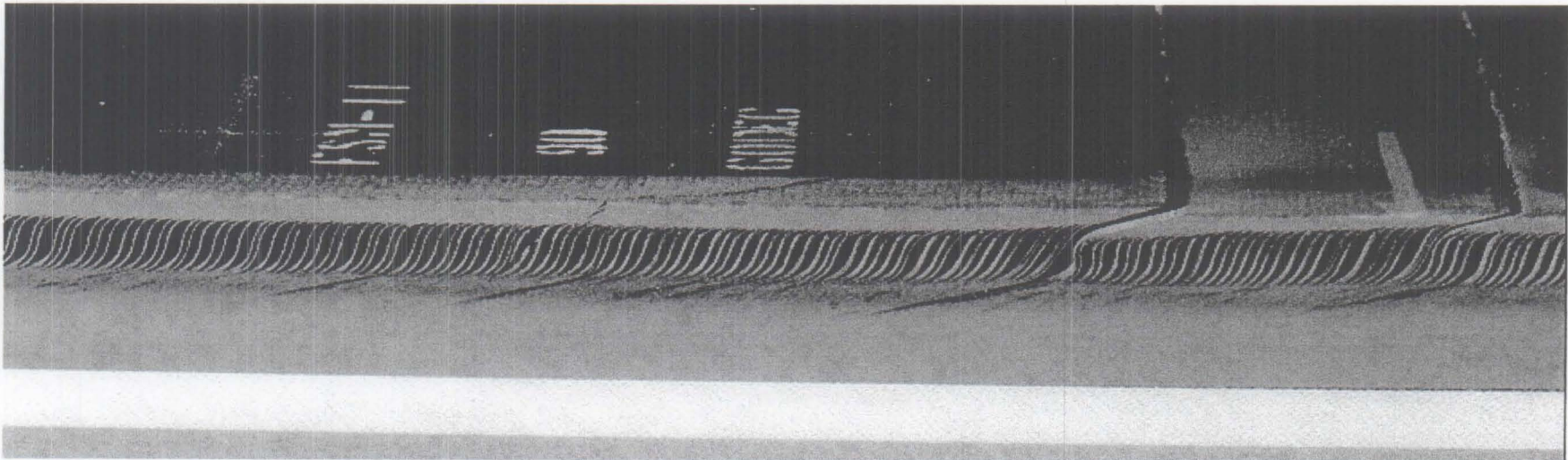
MATT failure criterion approved by NASA for public release and documented in AIAA Journal, Journal of Adhesion, and proceedings for AIAA JPC and Adhesion Society Meetings

- Ablative composite liners
 - Surface temperatures approximately 4,000 deg. F
 - Material “ablates” during motor operation
 - Ablative required to insulate metallic structure of nozzle
 - Anomalous performance not acceptable for man rated system



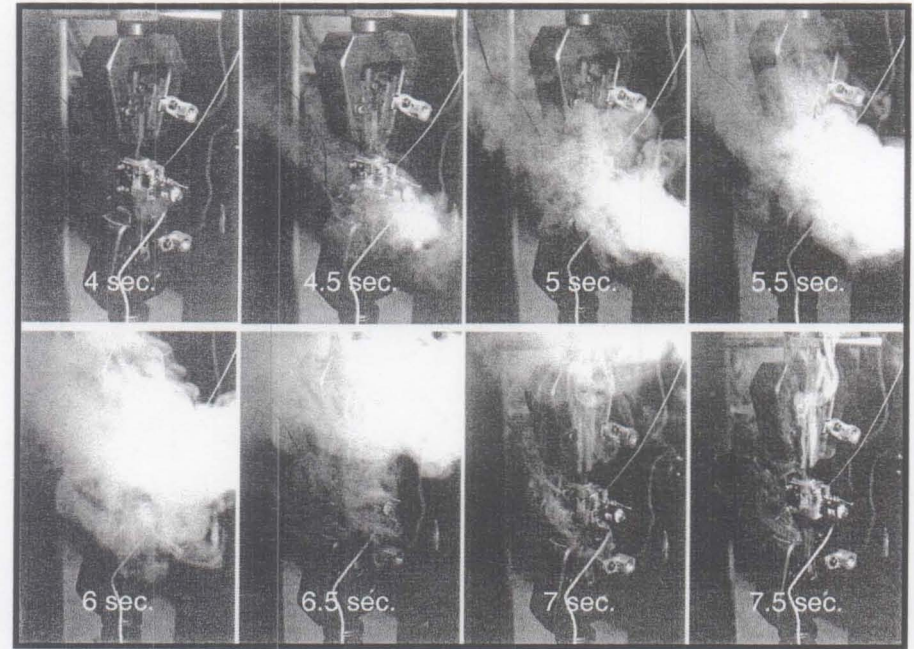
Ply lifting in heated ablative liners is a well known phenomenon documented in many technical journals (e.g. AIAA, JANNAF, etc).

- Ply lifting has been an issue for numerous years
 - Involves lifting of char cap
 - Questions arise about integrity of the char cap and its ability to insulate
 - Need for analytical model of behavior



Ply lifting in heated ablative liners is a well known phenomenon documented in many technical journals (e.g. AIAA, JANNAF, etc).

- Analytical modeling of heated phenolics
 - Need material properties as a function of
 - Temperature
 - Time
 - Degree of char
 - Material changes
 - Need to include effects of
 - Pyrolysis gasses (smoke)
 - Coupled analyses
 - Thermal (affected by pyrolysis gas flow)
 - Flow (affected by structural deformations)
 - Structural (affected by thermal and flow predictions)

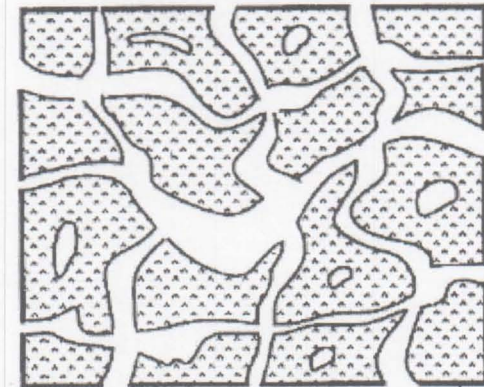


Testing Conducted by Landers and Singer

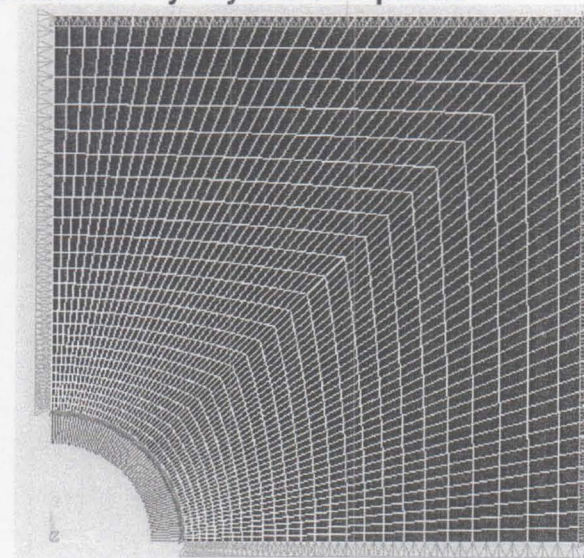
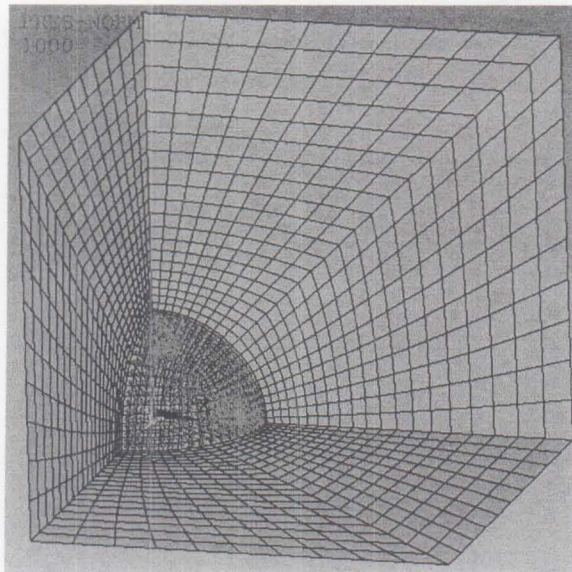
Ply lifting in heated ablative liners is a well known phenomenon documented in many technical journals (e.g. AIAA, JANNAF, etc).

- Analytical modeling of heated phenolics
 - Need to account for the presence of porosity
 - Need to model effects of pressure loading in pores
 - Pores can be many shapes
 - Most likely elongated along direction of fibers

Pyrolyzed Composite



Models of Porous Media – Estimate for Pyrolyzed Composite

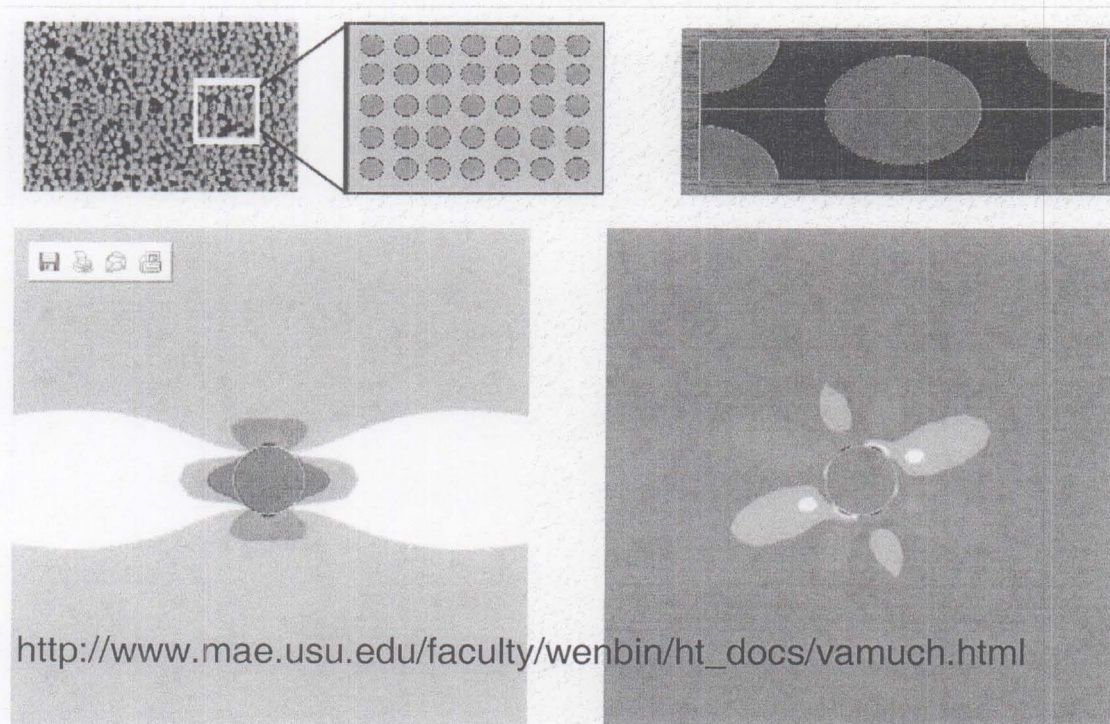


Ply lifting in heated ablative liners is a well known phenomenon documented in many technical journals (e.g. AIAA, JANNAF, etc).

- Analytical modeling of heated phenolics
- Need for coordination with Universities
- Need for programs such as VAMUCH

VAMUCH

A General-Purpose Micromechanics Code



VAMUCH is coordinated by
Dr. Wenbin Yu of Utah State
University

- ATK Launch Systems has wide variety of engineering opportunities
- NASA programs involve new and developing technologies
- Promontory plant at ATK is heavily involved in supporting science and engineering
- Nozzle engineering has unique challenges to address
 - Design of new launch systems
 - Adhesive modeling is complex and state-of-the-art
 - Composite ablative liner studies allow for advancing science in the rocket motor industry